An X-Band Radiometer for the Microwave Weather Project

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A stabilized high-resolution X-band radiometer has been designed, constructed, and is presently operating at the Venus Deep Space Station in the Goldstone Deep Space Communications Complex in California. The radiometer is an automatically switched and automatically calibrated noise-adding radiometer and is used for atmospheric propagation research for the Microwave Weather Project. This report describes the radiometer, its sensitivity, and gives examples of its performance.

I. Introduction

The Microwave Weather Project forms part of an overall Radio Systems Development Project which seeks to optimize the spacecraft-to-ground communications link. The objective is to provide a mathematical model of atmospheric transmission at X- and K_u-bands. This model will allow practical predictions of link performance to be made and will also form the basis of a specification of the receiving sensitivity of a Deep Space Network ground station. The model, which contains both probabilistic and deterministic elements, is based on the statistical correlations of weather and communications capability at X- and K_u-bands. Previous reports (Refs. 1, 2) have discussed the Microwave Weather Project and described the method and equipment used to build a suitable data base from which the mathematical model can be designed. They also described the difficulty of acquiring sufficient data of good quality using the existing X- and K_u-band radiometers on the 64-m antenna at DSS 14 at Goldstone DSCC.

In order to improve both the quantity and quality of the X-band data, a radiometer has been designed, built, and installed at DSS 13. This radiometer is a high-precision instrument that is dedicated to the Weather Project and which operates 24 hours-per-day automatically collecting data. This report describes this radiometer and its method of operation.

II. The Equipment

Figure 1 shows a block diagram of the X-band radiometer. The antenna is a corrugated horn which is directly coupled to a waveguide switch. The switch can connect the receiver to the horn, an ambient termination or a liquid nitrogen-cooled termination. The horn is built to the same design as the X-band horns used in the X-band radar, transmit-receive; K-band receive (XKR) cone on the 64-m antenna at DSS 14 and the Multiple Frequency X- and K-Band (MXK) cone which preceded it on the antenna. The gain of the horn is 22.3 dB; the dissipation loss in the horn contributes 1K, +0.5, −0.25 (K) in noise temperature; the 3-dB beamwidth is 7 deg (half angle) and the gain is down 10 to 12 dB at a half angle of 15 deg. The receiver is a mixer and IF amplifier, the output of which feeds a detector which has been described in several previous reports, (Refs. 3–6). The computing counter and programmer form a noise adding radiometer (NAR), (Ref. 7), whose noise diode feeds into the receiver through a coupler, as shown in the diagram. The output from the NAR feeds a data acquisition system, which is described elsewhere. The block diagram shows that two local oscillators (LO) are available, only one of which is used at a time. These two solid state LO's are set a few hundred megahertz apart, which allows ample frequency agility to avoid interference by microwave communication links or X-band transmitters. The LO presently in use is set at 8498 MHz.

The noise diode and its input coupler, the receiver, the local oscillators and all the interconnecting lines between these items are all temperature controlled to ±2°C in an environmental enclosure. This is shown schematically in the diagram.

In normal operation the radiometer is automatically switched between the horn and the ambient load. This is an additional calibration capability and is described in the next section. The liquid nitrogen-cooled load is not used in routine operation; it is a precision calibration tool which is used manually, approximately once per month.

The waveguide system and horn are pressurized with dry nitrogen gas. The radiometer is enclosed in a suitable box, which is mounted on an elevation-over-azimuth electric antenna drive. Figures 2 and 3 are photographs of the system.

III. Calibration by the Cryogenic Load

A precision calibration using the cryogenic load is carried out manually at periodic intervals. This serves primarily to calibrate the noise temperature of the noise diode (T_N). Regular measurements of T_N will keep a check on the noise diode aging, and thus remove the possibility of these effects (or other slow drifts) from contaminating the data quality. The calibration is carried out by adjusting the value of T_N so that the NAR output corresponds with the calibrated thermal noise temperature of the cryogenic load when the receiver is connected to this load.

IV. Routine Operation

In routine operation the waveguide switch is automatically controlled by the NAR programmer to switch the receiver to the horn for one minute and then to the ambient load for one minute. This cycle is repeated continuously during normal operation.

With the receiver connected to the ambient load the NAR measures a system operating noise temperature in kelvins (T_{op}), such that

$$T_{op}|_{load} = T_E + T_P \tag{1}$$

where

T_E = receiver front-end excess noise temperature (K)

T_P = physical temperature of the ambient load (K).

The reference plane for T_E is the input to the waveguide switch. T_P is measured by a quartz thermometer in the ambient load and therefore the programmer can solve for T_E. The value for T_E is calculated every second minute when the receiver is connected to the ambient load.

When the receiver is connected to the horn the NAR measures a system operating noise temperature ($T_{op}|_{horn}$) such that

$$T_{op}|_{horn} = T_{atmos} + T_E + T_C + T_H \tag{2}$$

where

T_{atmos} = noise temperature due to the atmosphere (K)

T_C = cosmic background temperature (K)

T_H = noise temperature due to horn losses and a waveguide component, consisting of a stepped transition from circular to rectangular guide and about 3 cm in length, and any possible mismatches (K)

The values for T_C and T_H are assumed constant,

$$T_C + T_H = 2.7 + 1.7 = 4.4 \text{ K} \tag{3}$$

T_E has been automatically measured and calculated by the NAR from Eq. (1) and therefore the NAR computes the noise temperature due to the atmosphere by

$$T_{atmos} = T_{op}|_{horn} - (T_E + T_C + T_H) \tag{4}$$

On a clear day with the horn at zenith the atmospheric noise temperature is usually about 2.6 K.

V. Radiometer Sensitivity

The sensitivity of the NAR has been shown (Ref. 7) to be:

$$\Delta T_{min} = \frac{2\,T_{op}\,(1 + \frac{T_{op}}{T_N})}{(\tau B)^{1/2}} \text{ kelvins} \tag{5}$$

where

B = detector bandwidth, Hz

τ = equivalent integration time of the output integrator, sec

The bandwidth of the system is presently set at 20 MHz (10-MHz double sideband centered at 8448 and 8548 MHz). T_{op}, with the receiver connected to the horn, is approximately 600 K, and with the receiver connected to the ambient load, T_{op} is approximately 900 K. In either position the NAR switches the noise diode on and off 130 times in 52 sec. Thus 130 T_{op} measurements are calculated and averaged every minute. The equivalent integration time is therefore 52 sec. The NAR measures T_P both before and after each set of 130 Y-factor measurements on the ambient load. These two T_P measurements are averaged and used in the calculation for T_E. T_N is presently set to 1300 K. With these parameters the system sensitivity becomes (from Eq. (5)):

$$\Delta T_{min}\big|_{load} = 0.09 \text{ K}$$

$$\Delta T_{min}\big|_{horn} = 0.05 \text{ K}$$

so that the combined sensitivity (or resolution for relative atmospheric measurements, $\Delta T_{min}\big|_{atmos}$) is 0.1 K.

Figure 4 shows two elevation profiles made at DSS 13 on Aug. 4, 1975 with the horn tipping to the South (azimuth 180 deg). Atmospheric noise temperature in kelvins is plotted against elevation angle in degrees. The solid data points were made at 10:00 a.m. PST in clear sky; the open data points were made at 3:00 p.m. PST with some thin clouds to the south.

VI. Conclusions

A stable radiometer with high resolution has been constructed at X-band for the Weather Project. It is presently operating 24 hours per day at DSS 13. The addition of a similar K_u-band radiometer is under investigation.

References

1. Reid, M. S., "A Description of the Weather Project," Technical Report 32-1526, Vol. X, pp. 116-122, Jet Propulsion Laboratory, Pasadena, Calif., August 15, 1972.

2. Reid, M. S., Booth, R. W. D., "Preliminary Analysis of the Microwave Weather Project Data for CY 1971," Technical Report 32-1526, Vol. XI, pp. 111-120, Jet Propulsion Laboratory, Pasadena, Calif., October 15, 1972.

3. Reid, M. S., Gardner, R. A., Stelzried, C. T., "A New Broadband Square Law Detector," Technical Report 32-1526, Vol. XVI, pp. 78-86, Jet Propulsion Laboratory, Pasadena, Calif., August 15, 1973.

4. Reid, M. S., Gardner, R. A., Stelzried, C. T., "Improvement in the Accuracy of the New Broadband Square Law Detector," Technical Report 32-1526, Vol. XVIII, pp. 94-98, Jet Propulsion Laboratory, Pasadena, Calif., December 15, 1973.

5. Gardner, R. A., Stelzried, C. T., Reid, M. S., "Radiometric Applications of the New Broadband Square Law Detector," Technical Report 32-1526, Vol. XIX, pp. 89-92, Jet Propulsion Laboratory, Pasadena, Calif., February 15, 1974.

6. Reid, M. S., Gardner, R. A., Stelzried, C. T., "A New Broadband Square Law Detector," Technical Report 32-1599 (to be published).

7. Batelaan, P. D., Goldstein, R. M., Stelzried, C. T., "A Noise Adding Radiometer for use in the DSN," Space Programs Summary 37-65, Vol. 2, pp. 66-69, Jet Propulsion Laboratory, Pasadena, Calif.

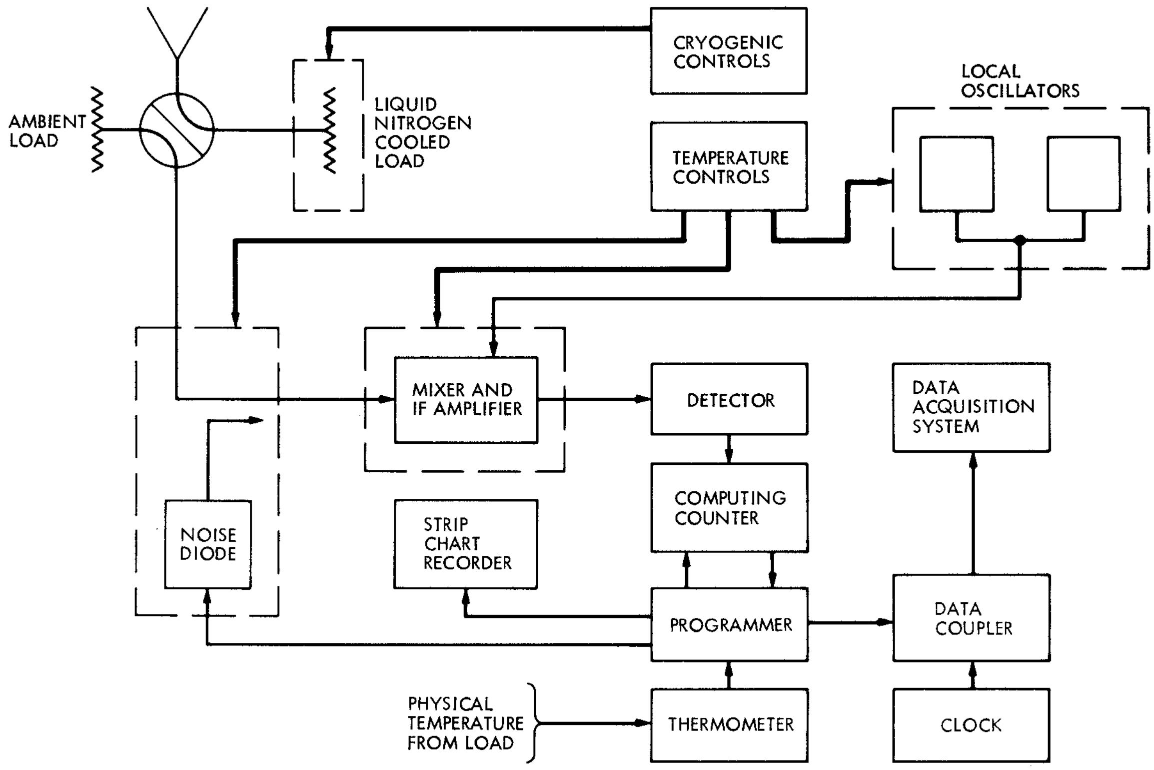

Fig. 1. Block diagram of the X-band radiometer

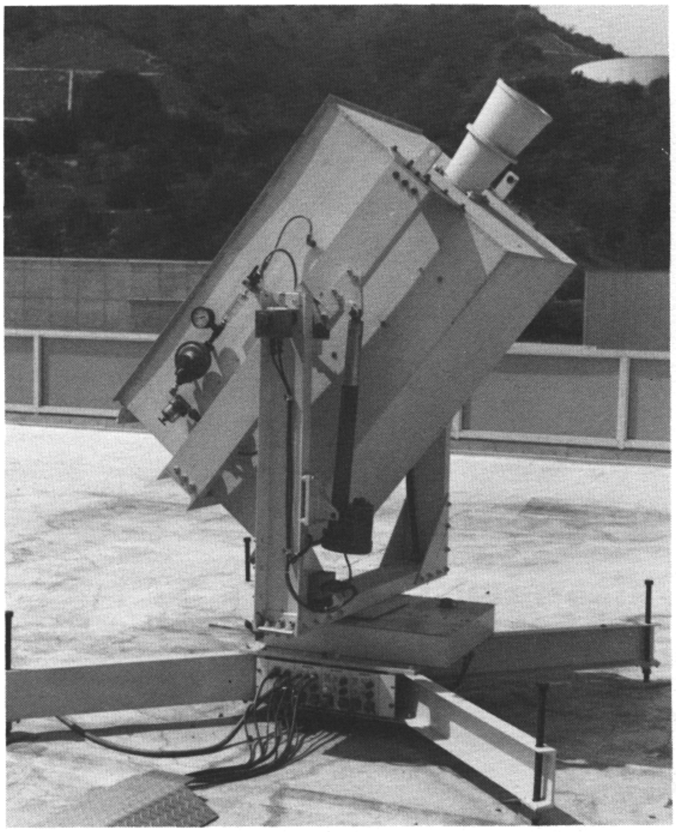

Fig. 2. Photograph of the X-band radiometer

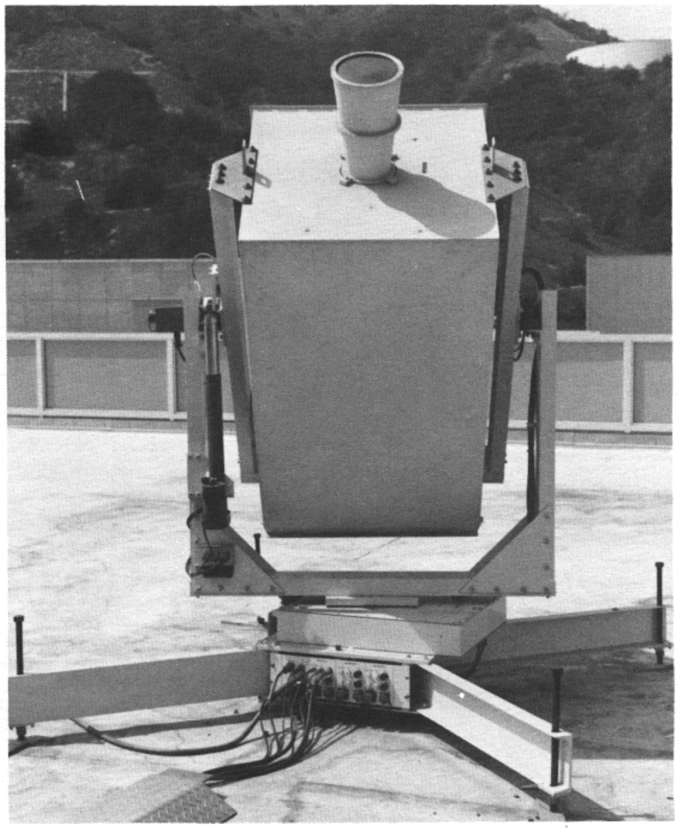

Fig. 3. Photograph of the X-band radiometer

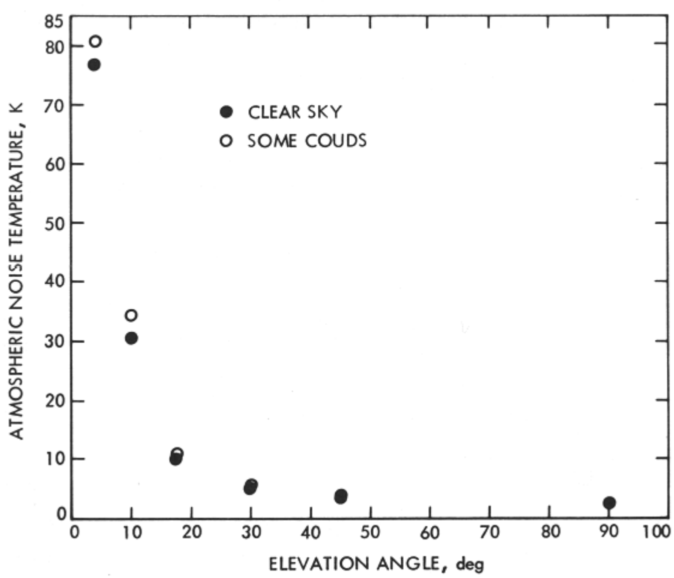

Fig. 4. Elevation profile of atmospheric noise temperature